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TECHNICAL REPORT NO. 70-5

DEVELOPMENT OF LP WAVE DISCRIMINATION CAPABILITY USING LP STRAIN INSTRUMENTS

Quarterly Report No. 6, Project VT/8706

by

James E. Fix
and
John R. Sherwin

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TELEDYNE GEOTECH
3401 Shiloh Road
Garland, Texas

30 January 1970

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ABSTRACT

The engineering model design of the strain/inertial complex is complete. The engineering model of the optical displacement transducer has been built and tests indicate that the design goals can be met. The short-term noise level is 3 x 10^{-9}m rms. Progress in preparation of the mine has been slow. The 55 deg azimuth horizontal tunnel is complete. The 325 deg azimuth tunnel is complete except for mounting holes for the instruments. The winze has been excavated down 26 ±2 ft. The fabrication of all equipment is complete except two displacement transducers. The second and third magnets have been received with stabilized flux of 1.187T and 1.180T. This flux and the coils on hand will give transducer generator constants of 33,600 V/m/sec and 37,300 V/m/sec. Installation is progressing in parallel with completion of the mine. The following seismographs have been installed and test recordings have been made at the corresponding magnifications given for X10 view of 16-mm film: short-period inertial - 500K at 1 sec; long-period inertial - 100K at 25 sec with 6 sec notch, 20K without notch; 55 deg azimuth horizontal strain - 1.4 mm/10^{-11} strain. The strain magnification will be increased after the mine is sealed and the seismometer is insulated. Numerous strain relief pulses were recorded several hours before a 4 kg rock fell from the mine wall. Single and dual pulses of strain have been recorded for local events (S-P time 11 to 13 sec) shortly after the P arrival and before the S arrival. Multiple strain pulses have been recorded in the latter part of a teleseismic surface wave train.

DEVELOPMENT OF LP WAVE DISCRIMINATION
CAPABILITY USING LP STRAIN INSTRUMENTS
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1. INTRODUCTION

This report discusses the progress during October, November, and December, 1969, in designing vertical and horizontal long-period (LP) strain seismographs with gain and response characteristics equivalent to those of the advanced LP inertial instruments. The designed instruments are to be used in conjunction with inertial seismographs to develop techniques for discrimination of LP seismic waves. The major effort on each task of the statement of work is discussed in separate sections. This report is to apprise the Project Office of the current status of Project VELA T/8706. It is submitted in compliance with Sequence No. A004 of the Contract Data Requirements List, Contract F33657-69-C-0121.

2. DEVELOP DESIGN SPECIFICATIONS, Task a(1)

No significant effort was devoted to this task during this reporting period.

3. DETERMINE THE MOST EFFECTIVE TECHNIQUE, Task a(2)

No significant effort was devoted to this task during this reporting period.

4. DESIGN, FABRICATE, AND TEST LABORATORY MODELS, Task b(1)

No significant effort was devoted to this task during this reporting period.

5. DEVELOP A FINAL ENGINEERING MODEL DESIGN, Task b(2)

With the completion of the engineering model optical displacement transducer, the last major effort on this task has been completed. Although further testing and minor modifications to the unit are still in progress, no further design work under this task is anticipated.

5.1 OPTICAL DISPLACEMENT TRANSDUCER, MODEL 32770

The design of the Optical Displacement Transducer, Model 32770, was completed early in this reporting period and fabrication of the engineering model was completed in October. Figure 1 shows the completed unit mounted on an Invar test fixture. Bench tests of the unit were started in November and several minor modifications were made to improve both operation and maintainability. Preliminary measurements indicate the design goals can be met.

5.1.1 Description

Figure 2 shows two views of the transducer with the cover removed. Most of the mechanical components shown are fabricated from Invar to reduce noise caused by expansion. The parts layout was kept reasonably straightforward to simplify maintenance and optical alignment in the field.

Figure 3 is the electrical schematic of the transducer. Vacuum phototubes were selected for the bridge circuit because of their better linearity and longer-term stability than similar gas-filled phototubes. The batteries used for the photocell supply voltages have very small current drains, which assure long life. An Analog Devices, Model 310, Varactor Bridge Operational Amplifier is used as a current amplifier to sense the very small imbalances in current caused by unequal illumination of the phototube cathodes. Exciter lamp power is furnished by a well regulated, dc power supply. Lamp voltage is maintained well below the rated level to increase lamp life and reduce power dissipation.

Figure 4 is a top view optical schematic of the transducer. Light from the incandescent lamp is collimated by the condensing lens assembly and passes through the first cylindrical lens. This lens forms the beam into a narrow bar of light and focuses it on a vertical slit mask. The mask eliminates scattered light and sharply defines the sides of the beam. The image of this mask is focused by the cylindrical lens relay assembly onto another mask situated in the middle of the corner reflector assembly. This mask defines the top and bottom of the beam, forming a sharp, bright rectangle of light. This rectangle of light is then focused by the objective lens assembly onto the beam splitter mirror. The beam is divided into two equal parts that fall on the cathodes of two phototubes.

5.1.2 Principles of Operation

In operation, the lamp, lens, and electronic assembly is mounted on the rock while the corner reflector assembly is mounted on the strain seismometer rod. If the corner reflector is displaced in a direction perpendicular to the major axis of the transducer as shown in figure 4, it can be seen that the beam entering the objective lens assembly is displaced twice that amount. The resulting unequal illumination of the photo-cathodes causes an unbalanced bridge, which is amplified and made available at the transducer output.

In theory, transducer sensitivity is directly proportional to the exciter lamp power and inversely proportional to the width of the first slit mask. The design is a compromise between these factors because increased lamp power increases undesirable heat dissipation, and slit masks narrower than one or two millimeters

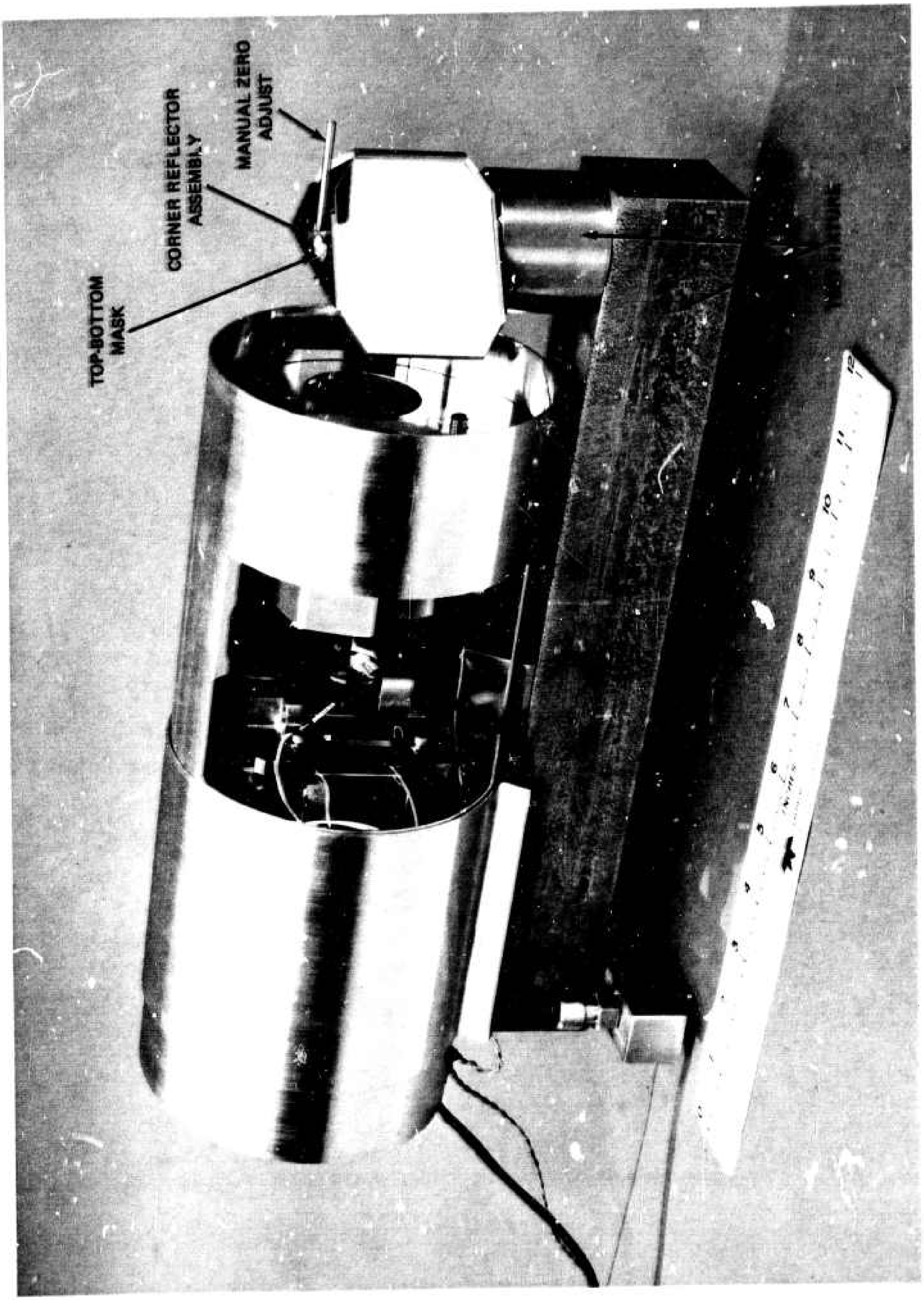

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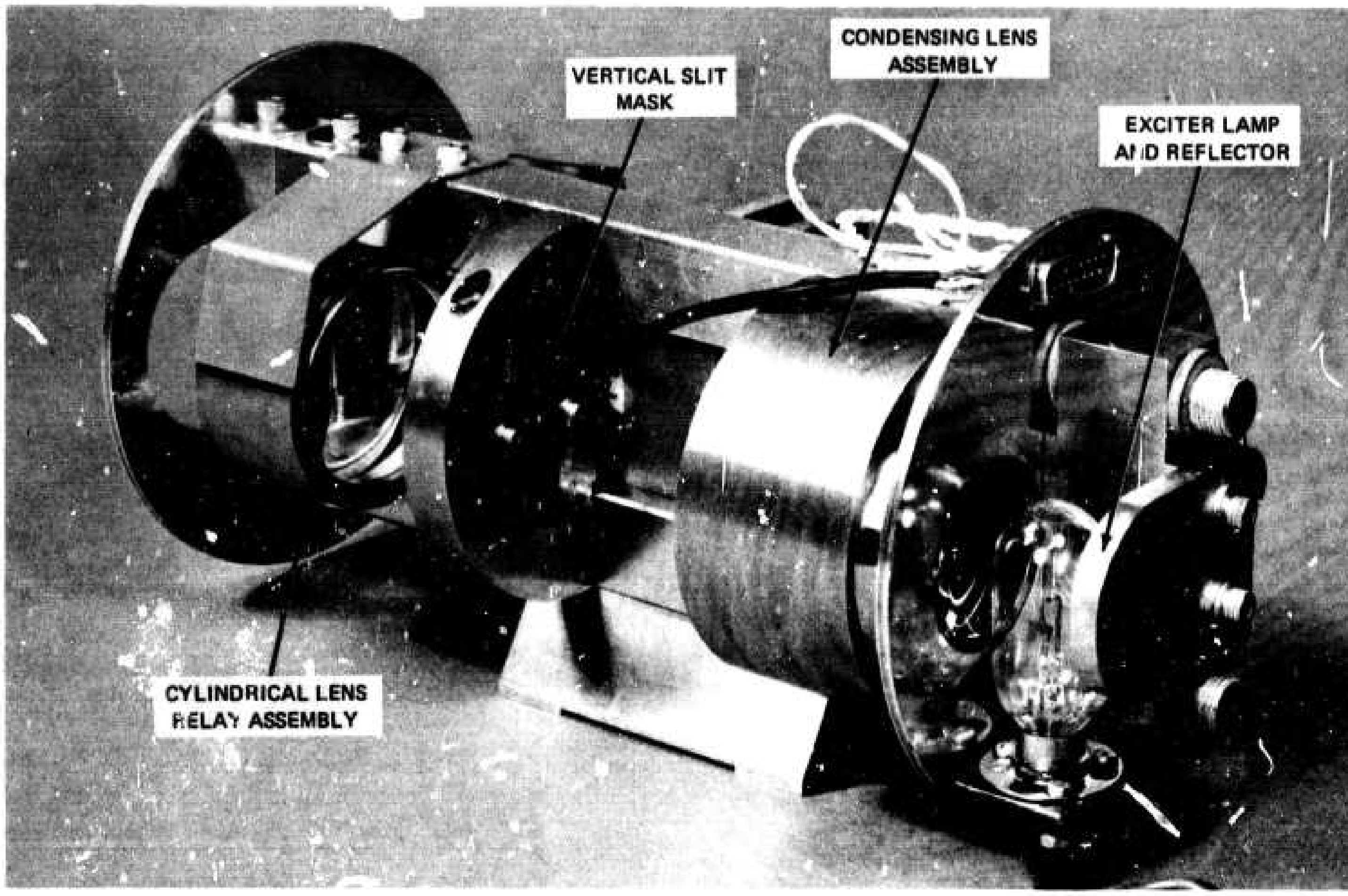
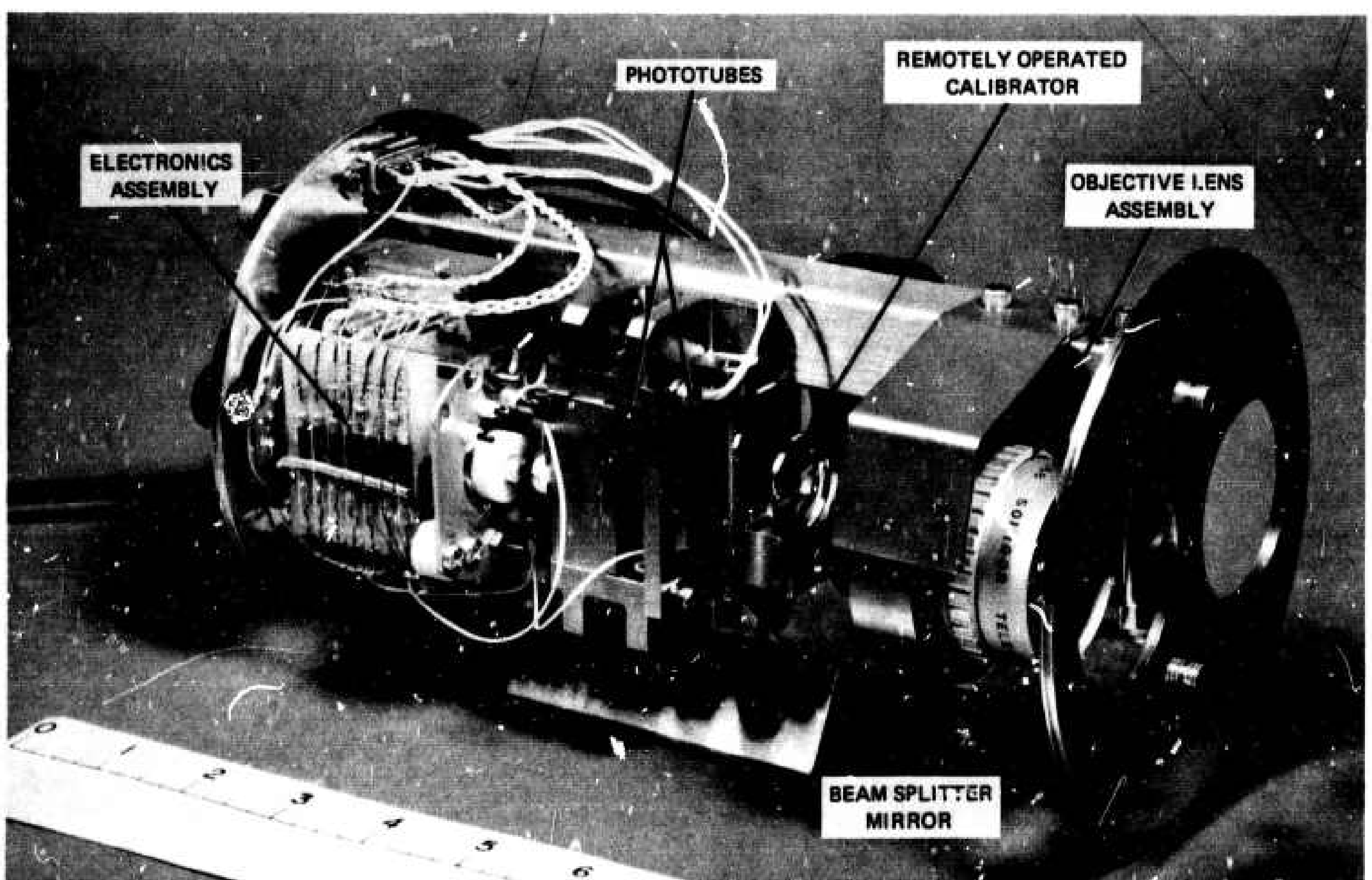
Figure 1. Optical Displacement Transducer, Model 32770.



(a)



(b)

Figure 2. Optical Displacement Transducer, Model 32770, with cover removed.

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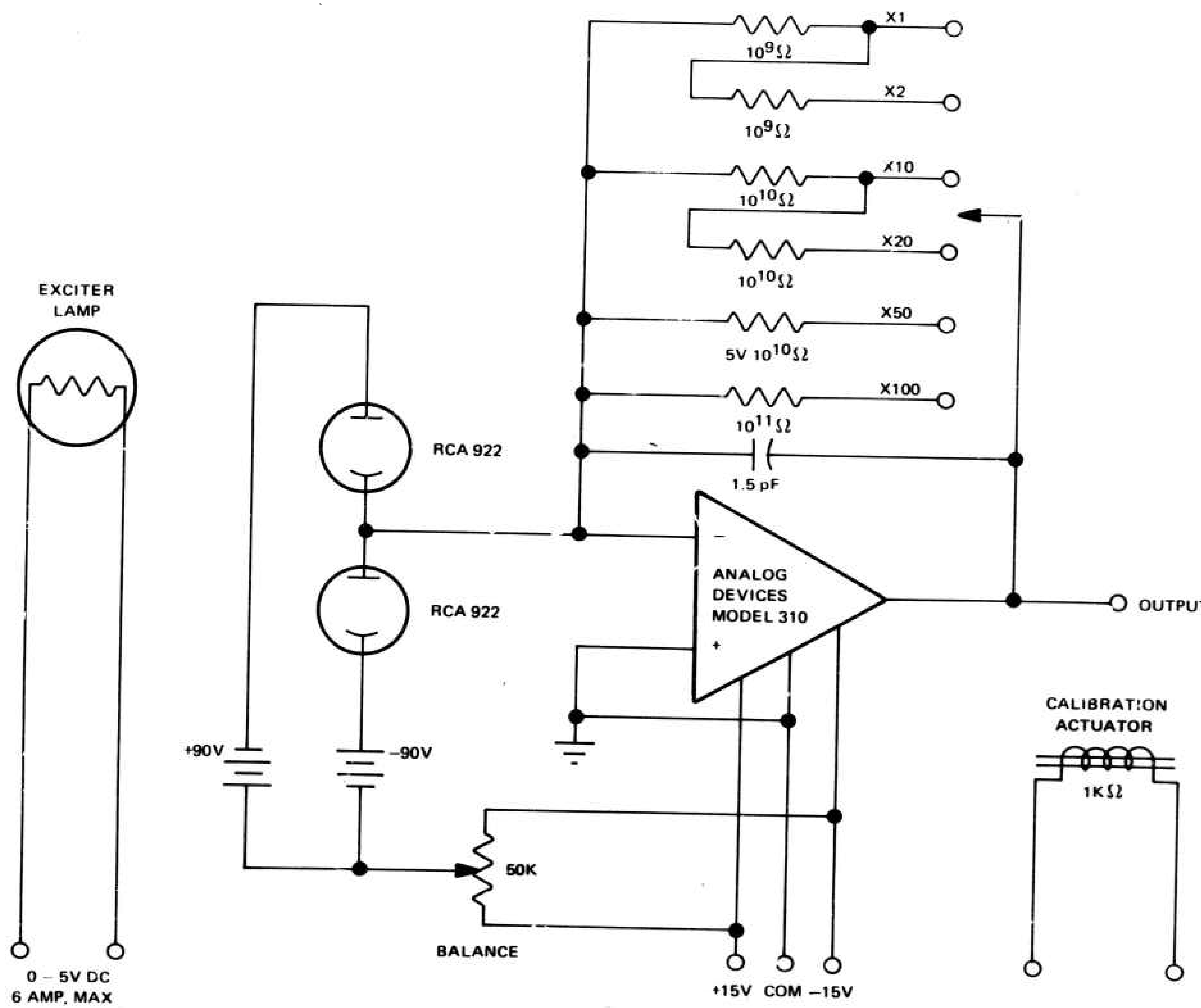

Figure 3. Electrical schematic of Optical Displacement Transducer, Model 32770.

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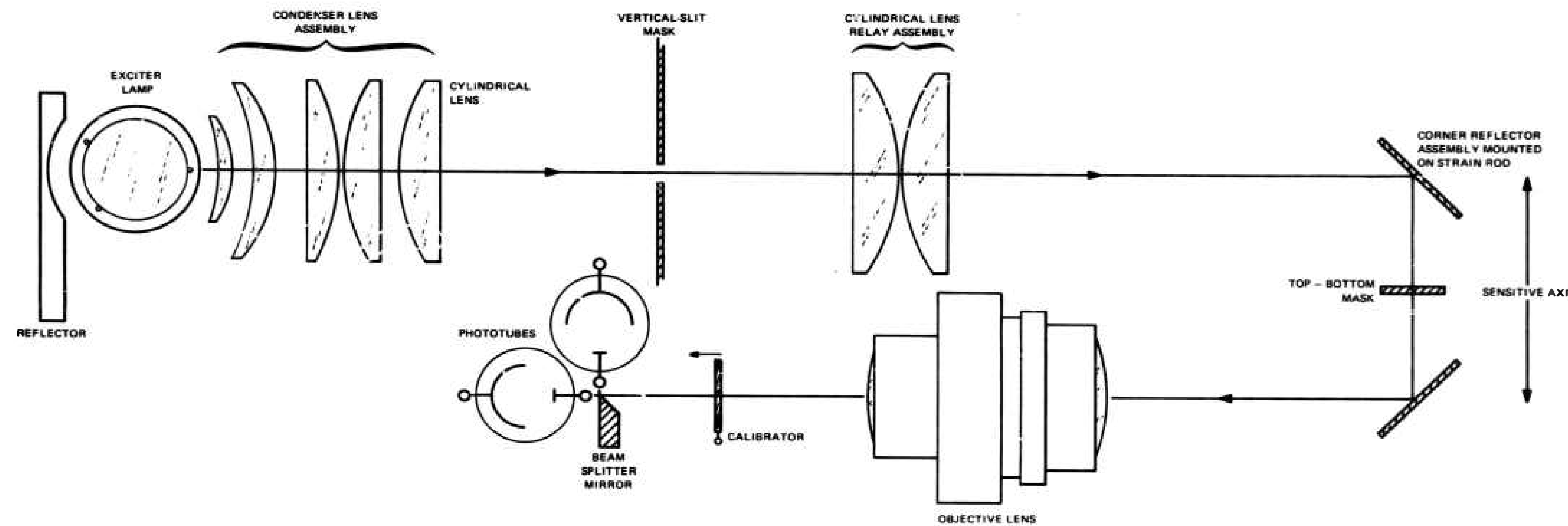

Figure 4. Top view optical schematic of the Optical Displacement Transducer, Model 32770.

require expensive, high-quality optics. On the other hand, instrument noise is determined primarily by the dark noise current of the phototubes and the Johnson noise of the photocell load resistance - in this case, the selected operational amplifier feedback resistor. In this circuit, the theoretical optimal noise level is achieved when the load resistance is between 10^9 and 10^{10} ohms.

5.1.3 Remotely-Operated Calibrator

The remote calibrator is an optical device used to periodically check the transducer sensitivity. It consists of a thin, flat piece of glass mounted at the pivot point of a relay-type actuator. The glass plate is placed in the optical path between the objective lens and the beam splitter mirror. When the glass is pivoted, the emerging light beam is laterally displaced a small amount due to the refraction of the glass. The amount of calibration displacement can be determined by measuring the angle of rotation or by comparing the calibration output to that produced by a known displacement of the corner reflector.

5.1.4 Test Results

Bench tests of the transducer began soon after the assembly was completed. It was immediately apparent that large noise voltages were produced by convection currents that changed the index of refraction of the air in the optical path. Therefore, all holes in the instrument case were covered and future tests were run using an insulated box to cover the instrument.

With the insulated cover in place and the lamp operated at half power of 16 watts, instrument temperature rose to about 55°C (120°F). Although the electronic components are rated at temperatures well above that level, methods of reducing the heat dissipation were sought, primarily to reduce heating of the surroundings that could cause noise in other instruments. Semiconductor light emitting diodes (LED's) operating at high-peak currents and relatively high frequencies were tested. The LED's were found capable of producing sufficient light at peak currents, but the short duty cycle necessary to prevent overheating required somewhat complicated sample and hold circuits in the transducer. When tests indicated that the transducer would operate satisfactorily with the incandescent lamp power below 10 watts, it was decided to delay further tests on this problem until the effects of such heat loads in the mine at Queen Creek, Arizona (QC-AZ) are determined.

Initial noise tests indicated that lamp voltage fluctuations produced as much as one hundred times greater output voltage fluctuations. Since power supplies capable of the required regulation (noise less than 1 mV) were expensive and impractical, other methods of reducing the noise were used. First, the sensitivity of the phototubes was matched as closely as possible - a task that proved somewhat difficult due to large variations between off-the-shelf phototubes. Secondly, the spectra of light reaching the two phototubes was balanced by improving the quality of the beam splitter mirror. These improvements greatly reduced short-term effects, but some longer-term noise was still evident. This longer-term noise was traced to expansion and contraction of the filament supports in the original exciter lamp, which was mounted horizontally. Incorporation

of the lamp shown in figure 2a, which has vertical filament supports, reduced these longer-term effects of lamp voltage fluctuations to acceptable levels.

After completion of the above modifications in late December, the transducer mounted on the test fixture was placed in the underground vault at Garland. The unit was insulated, power was applied to the electronics and the lamp, and the temperature was allowed to stabilize. Figure 5 is a portion of a strip chart recording showing a short-term noise sample and a calibration. The maximum short-term noise level is about 20×10^{-9} m peak-to-peak or about 3×10^{-9} m rms. The only long-term noise noted in tests thus far is a drift in one direction at a rate of about 10^{-7} m per hour. The drift rate seems to be decreasing very slowly. Transducer sensitivity is about 1.8 volts per 10^{-6} m at the lowest amplifier gain setting, and dynamic range is slightly greater than the 60 dB stated in the preliminary specifications.

5.1.5 Other Tests

Other tests are planned to determine the operating characteristics of the transducer. Short-term noise will be measured at several phototube load resistances and some reduction in this noise is expected. Long-term drift tests are continuing in the underground vault to determine if the drift is serious enough to warrant further modifications. Linearity and frequency response tests will be conducted after installation of the instrument in the mine at QC-AZ, where the strain calibrators can be used to produce the required sinusoidal inputs.

6. DESIGN A FIELD TEST INSTALLATION, Task b(3)

6.1 MINE PREPARATION

The preparation of the mine progressed slowly during the period covered by this report because of equipment breakdowns and personnel problems.

The first horizontal tunnel is complete. The second horizontal tunnel is complete except for the holes for the strain instrument mounts. Holes have been drilled in the floor to about 0.5 m depth for two side-by-side horizontal strain seismometers in the northwest end of the second tunnel. However, as these holes were drilled, it was found that the floor was fractured more than anticipated. Consequently, the holes will be deepened to about 1 m for the strain rod supports and to about 2 m for the transducer mount and the strain rod fixed end anchor. The fracturing on the floor is the result of two factors: (1) the floor surface contains fractured rock held together loosely yet strongly enough to resist being scooped up by the slusher (air-operated drag line) that removes the blasted rock and (2) even though the floor was finished with a light blast, more dynamite is necessary to lift the rock from the floor than is required to slab off a wall. It is recommended that in any future installations all horizontal strain seismometers be mounted on a wall to eliminate this problem. On the wall, the poorly cohesive rock will fall

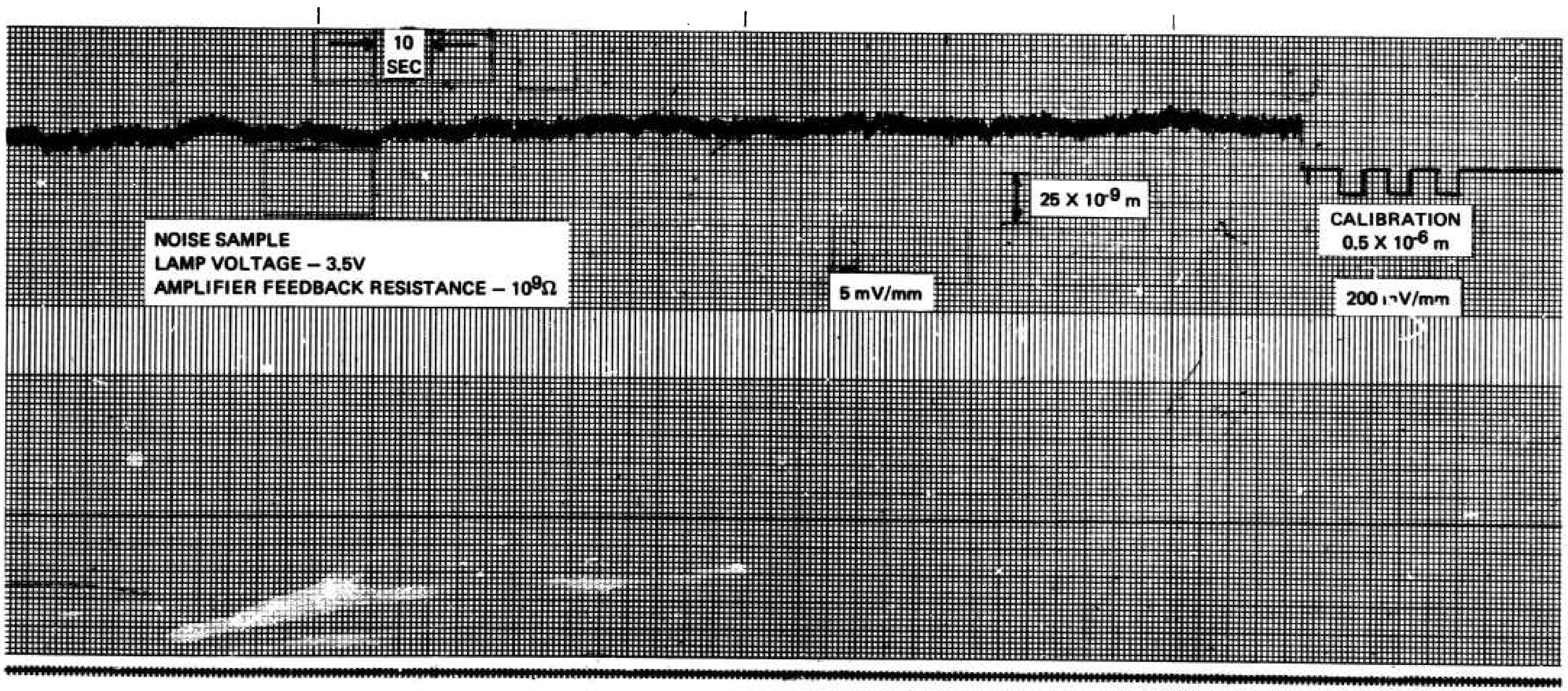

Figure 5. Noise sample and calibration record from Optical Displacement Transducer, Model 32770.

off or can be easily knocked off. Another big advantage of wall mounting is that the competent rock can be seen better, and a better choice of anchor and support points can be made. The 325 deg horizontal tunnel has remineralized faults at both ends. The faults intersect the tunnel at low strike angles and steep dips to the east. By installing the permanent strain seismometer on the floor next to the westerly wall, the full 40 m length can be obtained. However, the second strain seismometer that will be installed for the initial side-by-side tests will have the moving-coil transducer installed on one of the faults. To avoid this fault, would require shortening the length by about 6 or 7 m. Since the fault contains remineralization, there is cohesive material between the country rock and the brecciated zone. Therefore, by comparing the two side-by-side outputs, important information can be obtained for possible future strain installations on the effect of fault zones between the piers.

About 15 feet have been excavated up at the winze for clearance for the gallows frame. The winze was excavated down about 14 feet with the rock removed to a depth of about 8 feet by hand. The gallows frame, head pulley, bucket, and air-driven winch were installed. The rock from the last blast to the depth of 14 feet was then removed with the hoisting machinery. The next 7 feet required three small blasts to minimiz damage to the timbering from the flying rock. With each of the first two blasts there was a fair amount of damage and some time was required to replace the damaged timbers. The third blast was at a sufficient depth that no significant damage occurred to the gallows frame. Below this depth, normal rounds can be fired. On 31 December 1969, the winze was dug and rock removed to a depth of 21 feet. Holes for the next round were drilled 6 feet deep and the round was fired, but the rock has not been removed. It is expected that another 5 or 6 feet of depth was achieved. Timbers have been set to a depth of 12 feet and the next timber set is ready to install. The mining contractor is expected to resume work on a two-shift basis after the first of the year.

6.2 FIELD TEST INSTALLATION DESIGN

The installation of the three-component strain/inertial seismometer has been designed.

7. DESIGN, FABRICATE, AND INSTALL THE FIELD TEST INSTALLATION, Task c(1)

7.1 FABRICATE INSTRUMENTATION

The fabrication and assembly of the strain/inertial instrumentation is complete except for two of the optical displacement transducers. The second and third magnet assemblies were received from Indiana General Corporation, and have a stabilized flux in the gap of 1.187 T and 1.180 T. Magnets with these fluxes and the coils which have been wound will give generator constants of about 33,600 V/m/sec and 37,300 V/m/sec.

7.2 INSTALLATION OF THE STRAIN-INERTIAL COMPLEX

Installation of the instrumentation is progressing in parallel with completion of the mine. Figure 6 taken from the tailing pile shows the two recording vans, the access road, the power line, and the 52 spiral-four cables between the mine and the vans.

The three-component inertial SP seismometers have been installed in their final location in the 55 deg azimuth tunnel. No special treatment was given to their installation. They routinely operate on the 20-trace 16-mm film recorder at magnifications of 500K at 1 sec period.

The three-component inertial LP seismometers have been temporarily installed and all three components are routinely operating on the 20-trace 16-mm film recorder at magnifications of 100K at 25 sec with the Advanced Long-Period System (ALPS) high-gain response and at magnifications of 20K at 25 sec with the ALPS low-gain response. The three tanks for the LP seismometers have been installed. A groove was cut in the rock and the bottomless tanks were cemented in the groove. Before the tanks were cemented in place, the loose rock inside each tank was removed. Three holes were drilled, expansion bolts were installed in the holes, and steel plates were screwed onto the expansion bolts for the feet of the seismometers. The rock inside the tanks was covered with Colma Sol and painted with three coats of epoxy paint for an air seal. However, when the last blast was fired in the winze, the seal was destroyed. No cracks or pin holes are visible to the eye and it is assumed that there are numerous pin holes through the coatings and the joint sets in the rock. Further attempts to improve the tank seals are being deferred until after all of the mine modifications are completed.

A concrete pad has been poured and a shelf has been installed in the instrument room in the mine for the phototube amplifiers for the short-period (SP) and LP inertial seismographs (figure 7). The mass position monitors and controls and the free-period controls for the LP seismometers are installed in a rack in the instrument room seen on the left in figure 7.

The 55 deg azimuth horizontal strain seismometer has been assembled. The southwest end is shown in figure 8. The 2-inch (5.08 cm) outside diameter tube Invar strain rod is supported by a three-wire suspension. Elinvar wire was selected for the suspension because of its small temperature coefficient of Young's Modulus. The Elinvar wire is suspended from a square Invar frame. The frame is square to maintain vertical symmetry so that any temperature changes in vertically-stratified air will be uniform on both sides. The square Invar frame is bolted to an Invar adjustment plate that is bolted to two steel expansion bolts in the rock. The strain rod is supported every 5 or 6 feet to raise any spurious modes of vibration above the frequency range of interest. Figure 9 is a close-up of the velocity transducer and the Ithaco preamplifier. Figure 10 is the strain rod fixed anchor. A fourth expansion bolt will be added to the near lower corner of this anchor. Note the competence of the rock at both end points in figures 9 and 10. Also, note the effectiveness of the controlled blasting technique.

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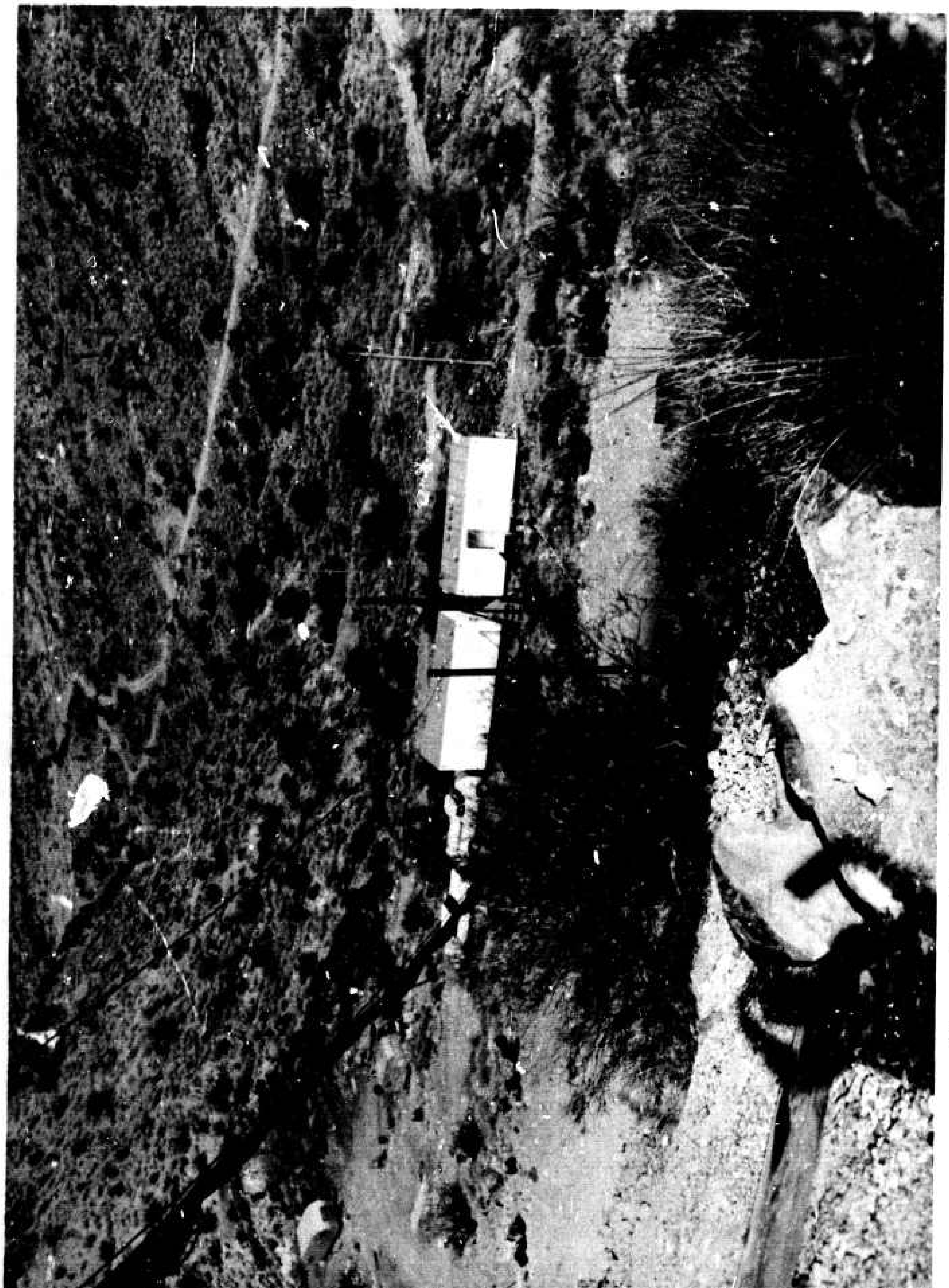

Figure 6. View from tailing pile showing cable line from the mine, recording vans, power line, and access road.

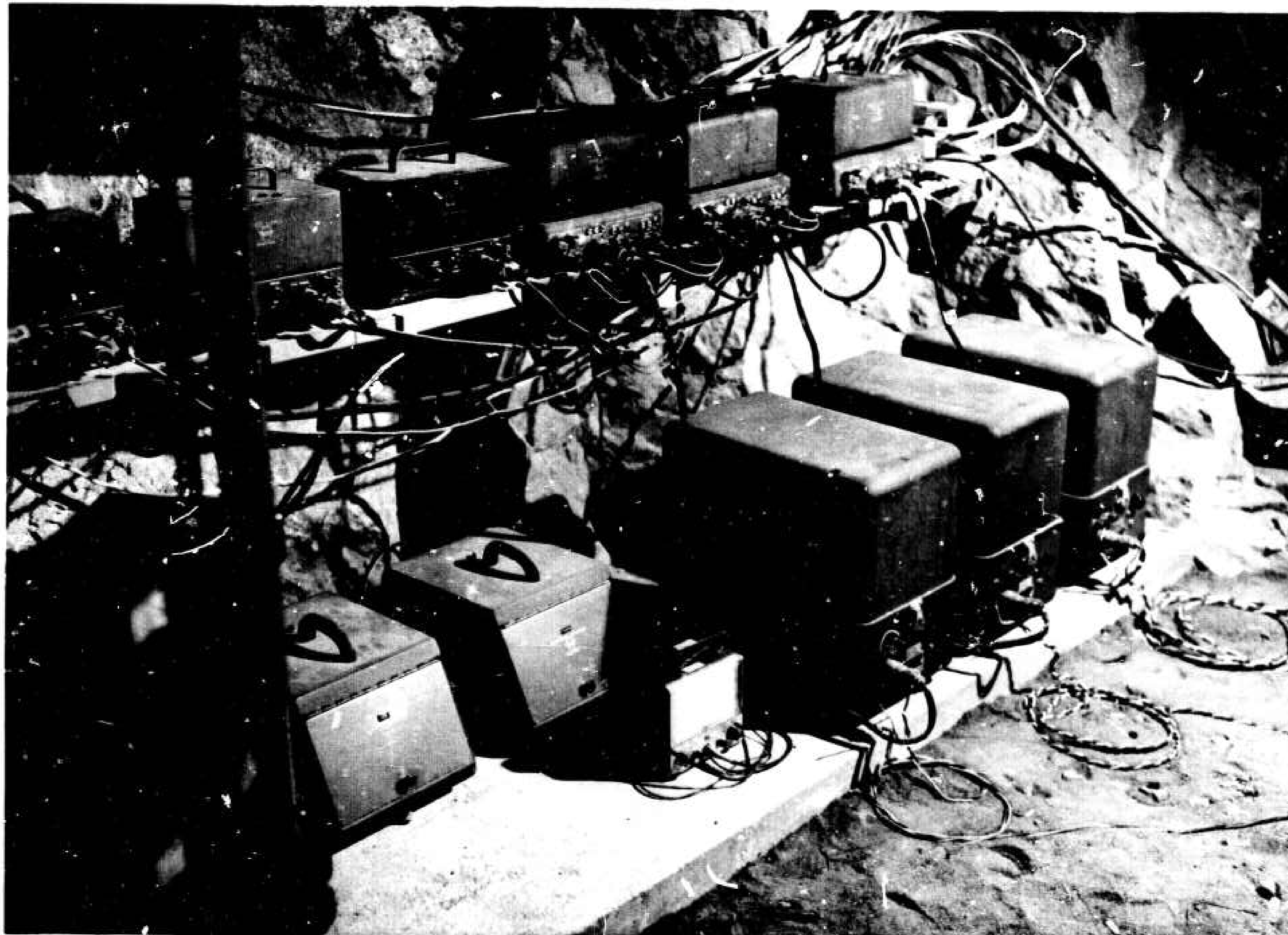

Figure 7. Phototube amplifiers and inertial LP seismometer controls in the instrument room in the mine.

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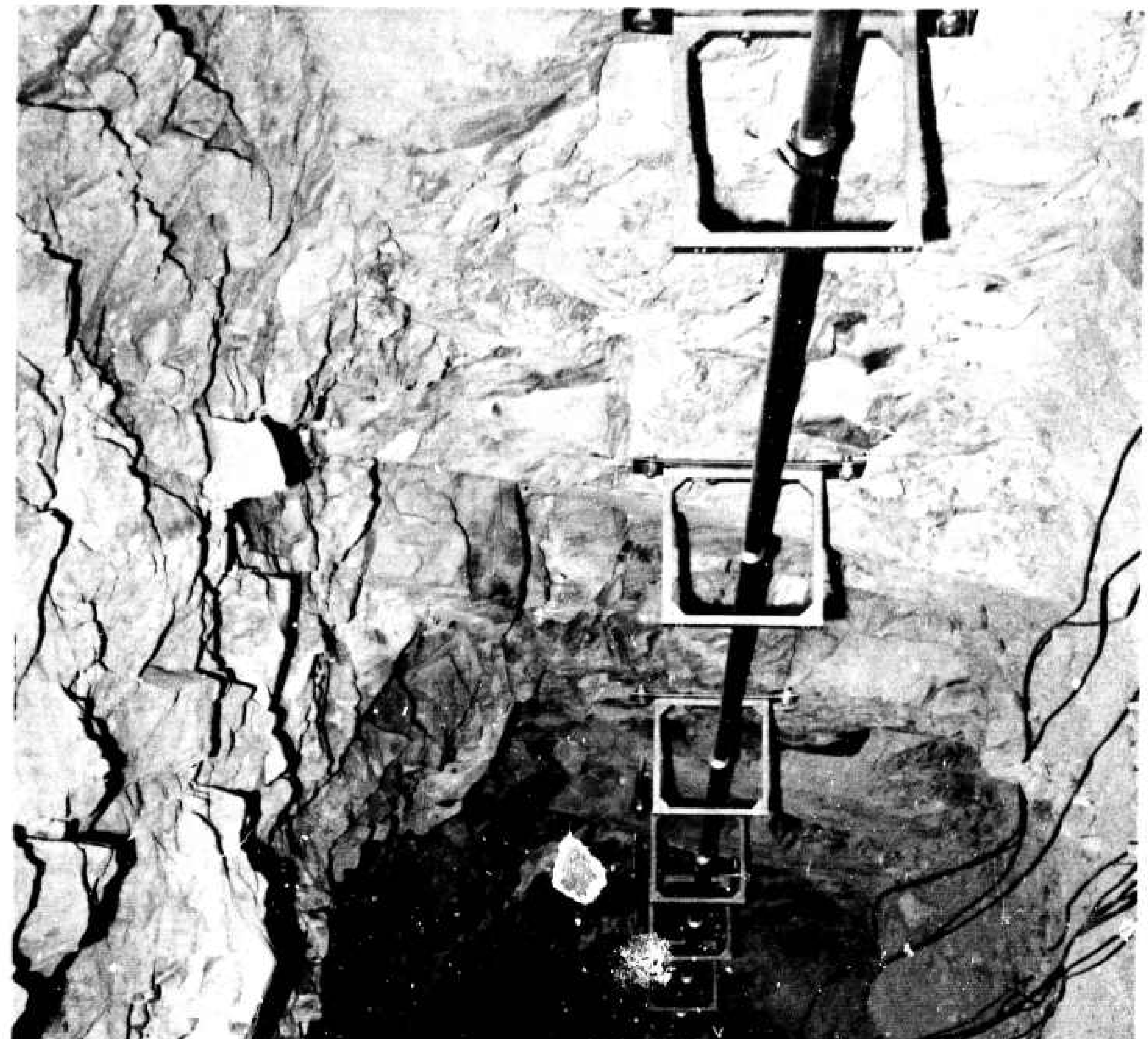

Figure 8. Southwest end of 55 degree horizontal strain seismometer.

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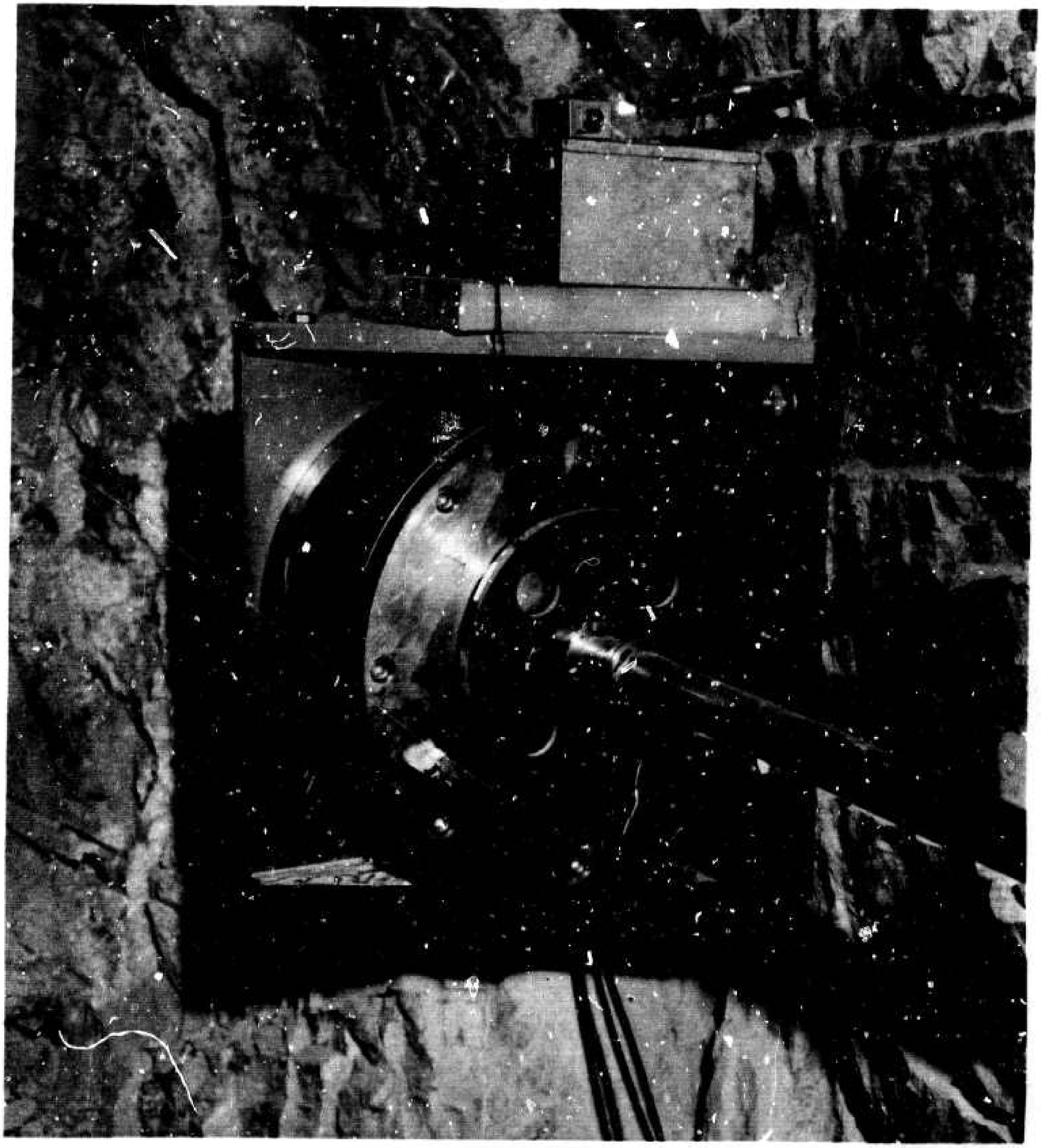

Figure 9. Velocity transducer and preamplifier.

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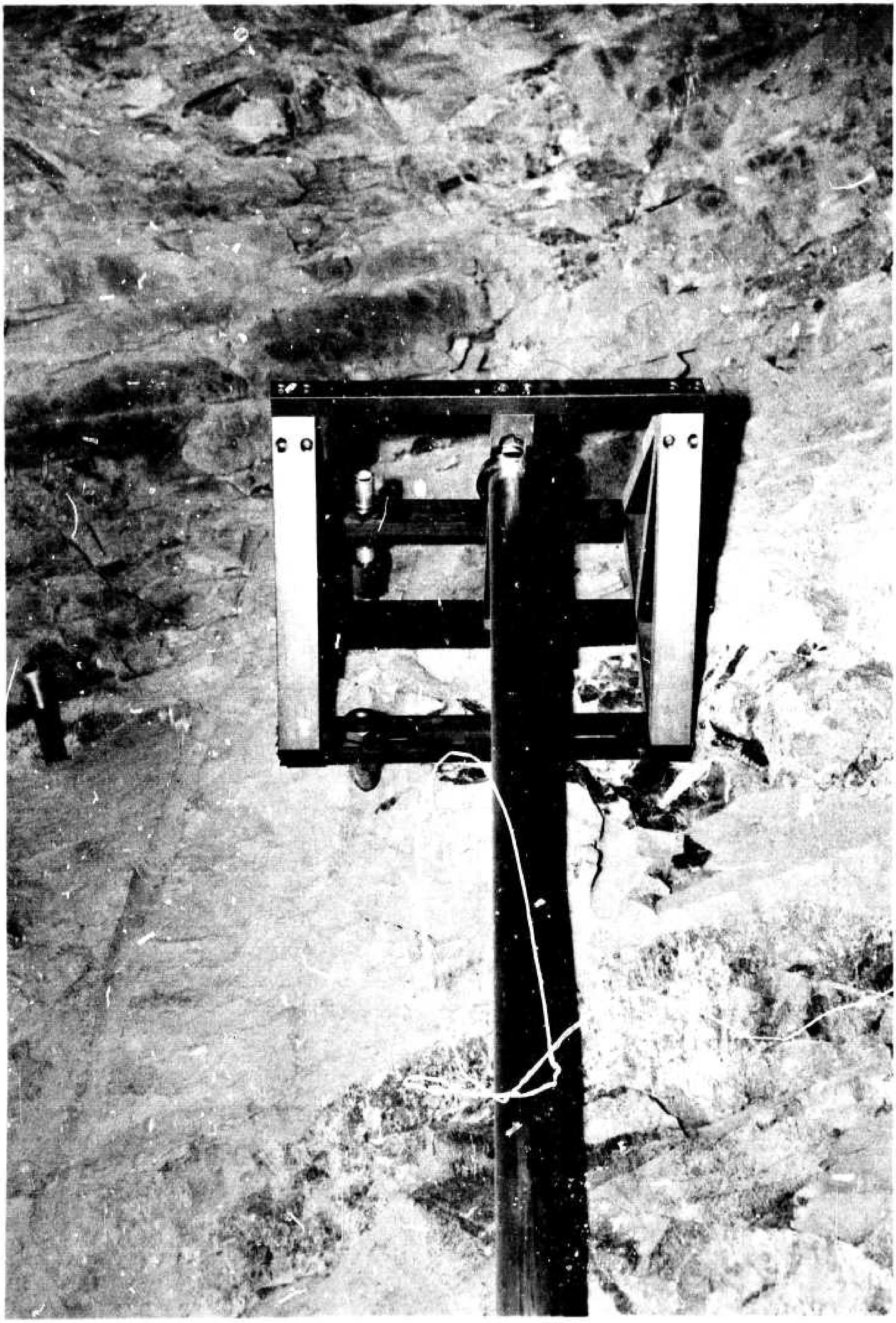

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Figure 10. Strain rod anchor.

Insulation for all three strain seismometers has been received at QC-AZ. A 4-inch thickness of polyurethane will be put around all the parts of the seismometers to reduce temperature variations within the passband of the seismographs to below 1 x 10^{-6}°C.

8. CONDUCT NOISE AND STABILITY TESTS, Task c(2)

The initial test seismograms are very encouraging. The mine is not sealed against air pressure fluctuations, and the LP inertial seismometers and the strain rod are not insulated. However, even with this lack of environmental control, the strain ALPS channel has been recorded at a magnification of about 1.4 mm/1 x 10^{-11} strain at 25 sec and X10 view. For a Rayleigh wave this is equivalent to a magnification of about 8.8K on an inertial system. The inertial ALPS channels have been recorded at a magnification of 17K at 25 sec with the low-gain response with the magnification limited by the 6 to 8 sec microseism background. When the mine ventilation blowers are turned on, all channels become unuseable. The only time that test data can be taken will be at times when the mine does not require ventilation.

There is a 30 to 70-sec disturbance on the S55L strain (see appendix for channel identification nomenclature) and P145L inertial seismograms that is thought to be either related to microbarometric pressure changes or to temperature changes associated with thermal convection currents. Recordings of these disturbances will be compared to the microbarograph recordings during January.

On 29 November 1969, about a 4 kg rock sloughed off the wall of the mine and hit a support frame on the 55 deg azimuth strain seismometer. The rock is shown in figure 11 being held in the location from which it fell. Figure 12 shows the recording on the S55L and S55S channels when the rock hit the frame. The system rang for about 16 minutes as illustrated in figure 13. For some time before the rock fell the stress relief and strain relaxation could be observed. Figure 14 shows a sequence of four pulses of strain. The pulses are all the same polarity and about the same amplitude. The fine character of the pulse on the SP S55S trace is not completely visible in this recording although a spike can be seen. The character on the LP S55L trace is clearly defined. After the rock fell and the mine and the seismometer again reached equilibrium, the pulses not associated with seismic arrivals almost ceased.

9. CONDUCT PRELIMINARY OPERATION AND EVALUATE INSTRUMENT PERFORMANCE, Task c(3)

Preliminary operation has been delayed by the continuing activity of modifications to the mine. Some evaluation of the instrument performance can be made during times when the ventilation blowers are turned off. However, the most meaningful evaluations will be made after the mine is sealed and the instruments are properly installed and insulated.

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Figure 11. Rock that fell onto support frame.

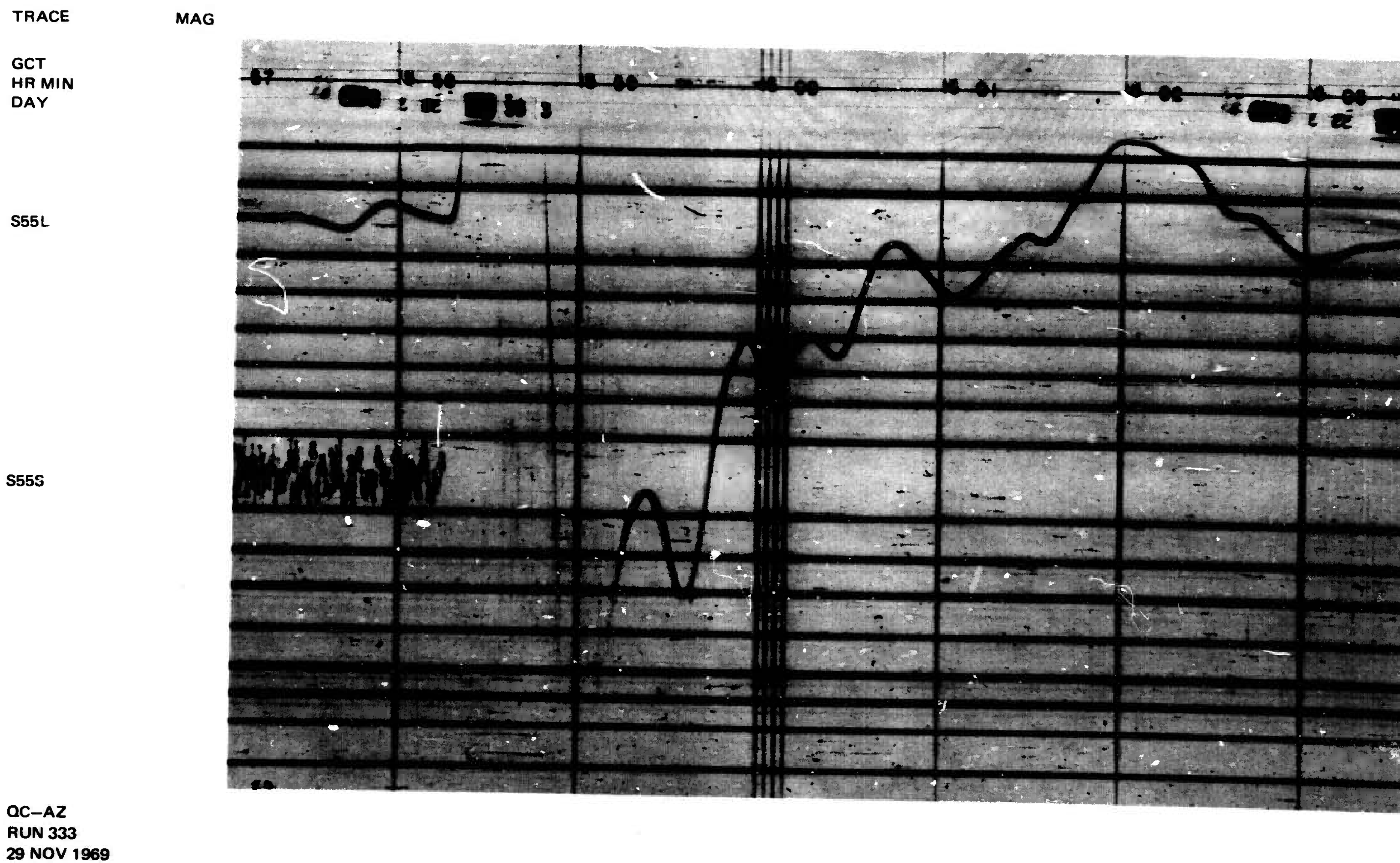

Figure 12. Reproduction of a 16-mm film record showing effect of 4 kg rock hitting strain seismometer support frame.

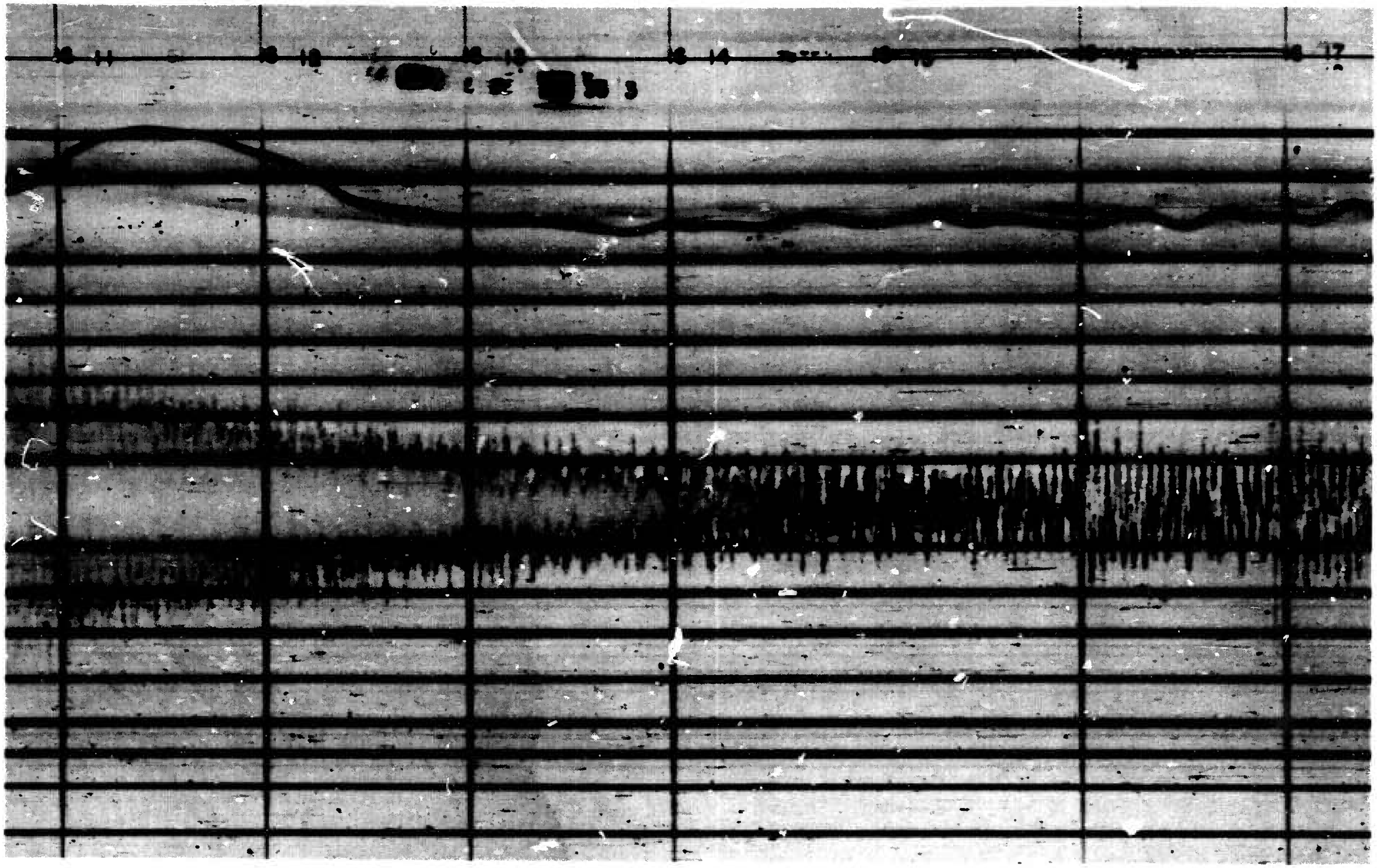

Figure 13. Reproduction of a 16-mm film record showing decay of oscillations of strain seismometer after it was struck by a rock at 1558:15.

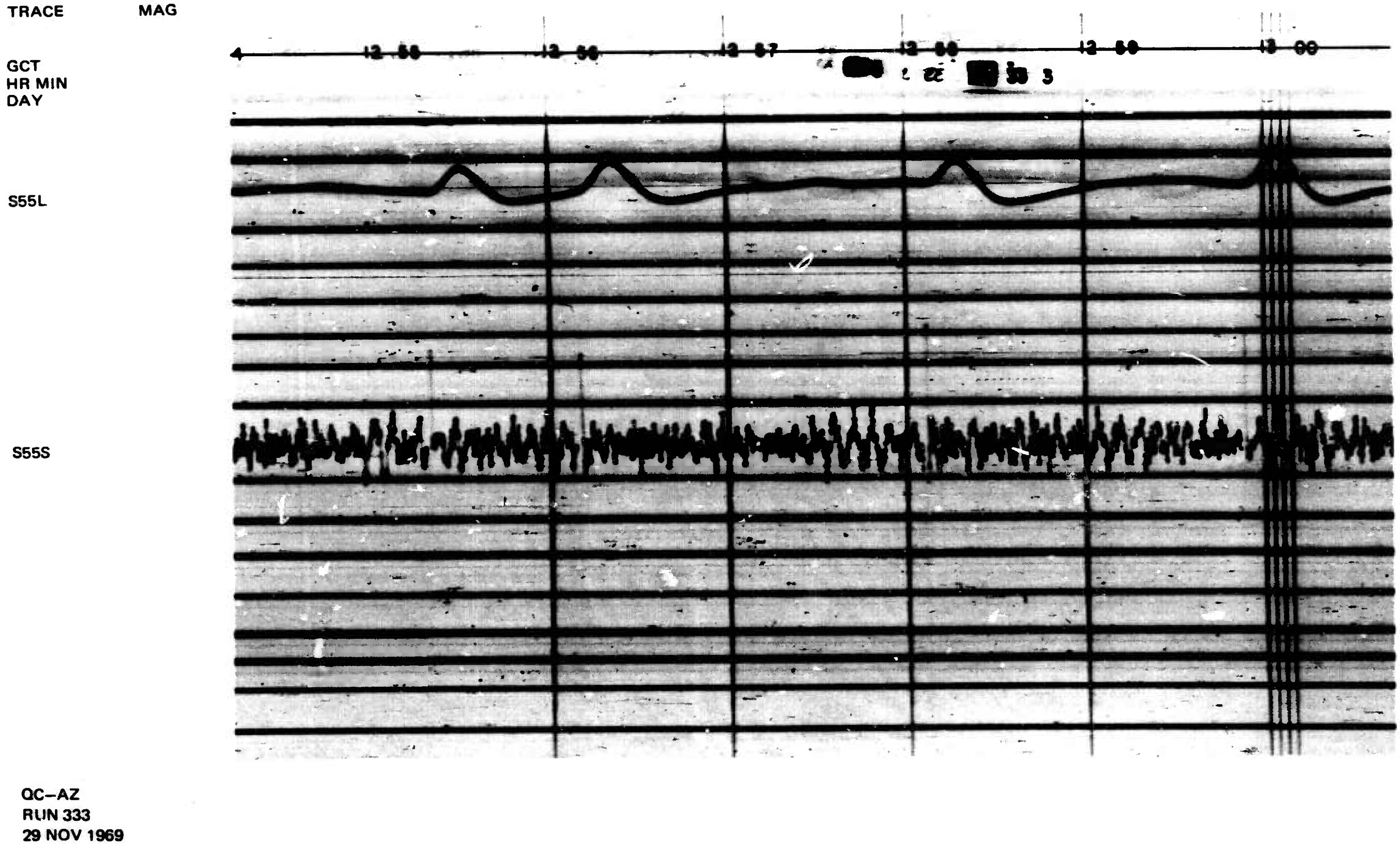

Figure 14. Reproduction of a 16-mm film record showing four pulses of strain 3 hours before a rock fell from the mine wall.

Pulses of strain are being recorded on the S55L ALPS response channel at the same time as arrivals from local and teleseismic earthquakes. Some of these pulses may be related to blasts in mines near Globe, Arizona. Insufficient data are available at the present for a detailed study of these pulses. More meaningful interpretations can be made when all three components of the strain seismographs are installed and the broadband and ultra-long-period (ULP2) channels are operational. However, from the pulses that have been recorded to date, it can be firmly concluded that all of the pulses are not pure single steps of strain. Quantitative character of the pulses has not been determined yet, but qualitative comparisons can be made between them by comparing times to the peak, first zero crossing, trough, and sometimes the second zero crossing. Figure 15 illustrates the recording of an earthquake reported by a Phoenix radio station as a magnitude 6 event near Globe, Arizona, on Christmas day. The LASA preliminary epicenter list did not report this event, and the USC&GS Preliminary Determination of Epicenter location has not been published yet. The city of Globe is about 85 km from QC-AZ. The first peak and the first trough were lost on the film, but the peak was up indicating rock compression. A pulse of strain was recorded at 1249:31. Note that a second independent pulse of opposite polarity was recorded at 1251:00. A complete interpretation of the second pulse cannot be made from these data, but it can be hypothesized that this was possibly a corrective rebound from an overshoot of strain relief from the primary earthquake, or a second pulse of the same polarity as the first and the initial peak is not visible on the recording, or a local disturbance triggered by the earthquake. At the time these recordings were made, the strain magnification was not accurately known so that the sum and difference traces are not correctly equalized between the strain and inertial seismographs. Even so, the character of the pulse on the sum and difference traces is different indicating some response of the P55L inertial seismograph. Another point of interest in all of these pulses is that the step or ramp function of strain is recorded 3 to 6 sec after the P-wave arrival and before the S-wave arrival (S-P times are about 11 to 13 sec). Wideman and Major (1967) reported a continental travel velocity of 3.0 ±0.3 km/sec for steps of strain. The reason for the difference between travel times from Globe to QC-AZ and those observed by Wideman and Major is not known. Figure 16 is a recording of an event with a similar S-P time to the larger event in figure 15 and may be an aftershock. The pulse of strain in figure 16 appears to be two steps (or ramp functions) of strain superimposed with a time interval of 11 sec between them. Figure 17 is a recording of a local event with an S-P time of 13 sec illustrating the recording of a single pulse on the strain ALPS seismograph beginning at about 3 sec after the P-wave arrival. Figure 18 is the recording of another apparent dual pulse of strain. The event in figure 18 is thought to be a mine blast in the Globe vicinity because of the S-P time and its occurrence between 2200 and 2400 when many similar events occur on most days. The P55L and P145L inertial seismographs also responded with the same period as the strain seismograph. The sum trace indicates some enhancement of the pulse and the difference trace indicates some cancellation. Figure 19 illustrates two pulses of strain recorded during the surface wave train of an event from an unknown location. Based on the arrival times of the body phases, this earthquake was at a distance of about 55 deg. If this distance is correct, the pulse at 0147:08 was recorded at a time corresponding to an average surface velocity of 1.8 km/sec. No previous investigators have reported multiple strain pulses associated with a single event. If the strain pulses are true radiations from a remote source, similar

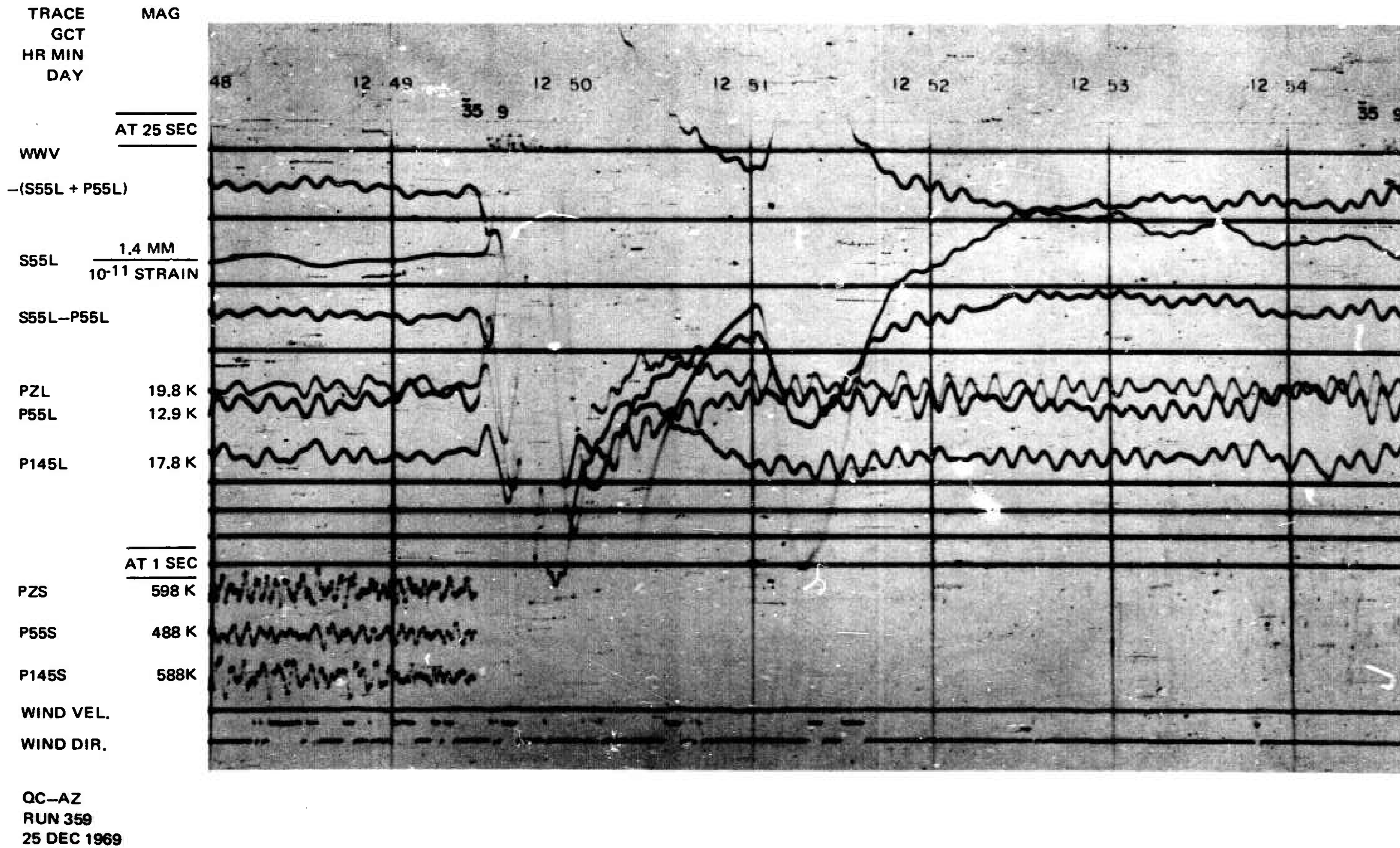

Figure 15. Reproduction of a 16-mm film recording of a large earthquake near Globe, Arizona, Δ = 85 ±10 km. Strain pulses occur at 1249:31 and 1251:00.

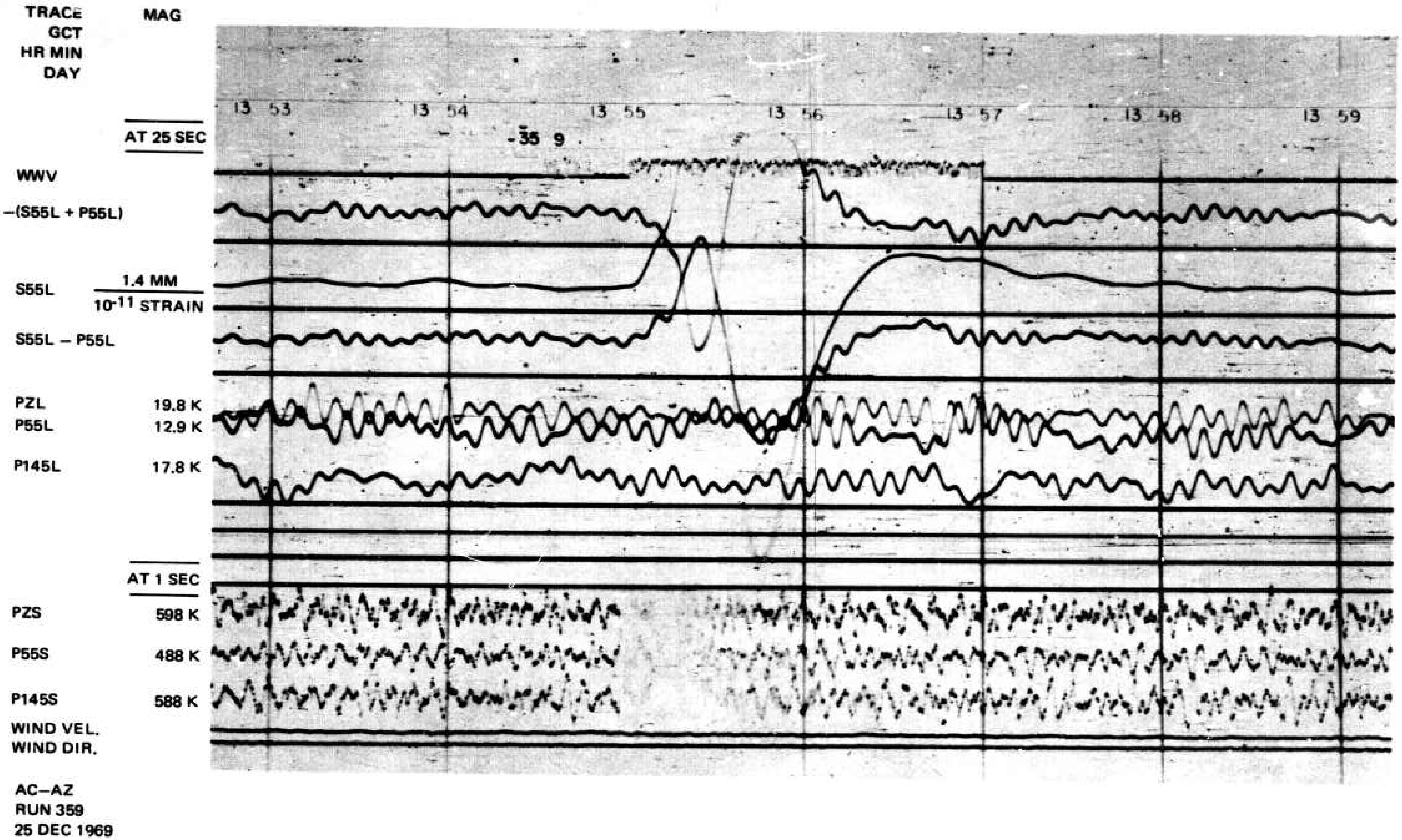

Figure 16. Reproduction of a 16-mm film recording of a local event. Strain pulses occur at 1355:02 and 1355:13.

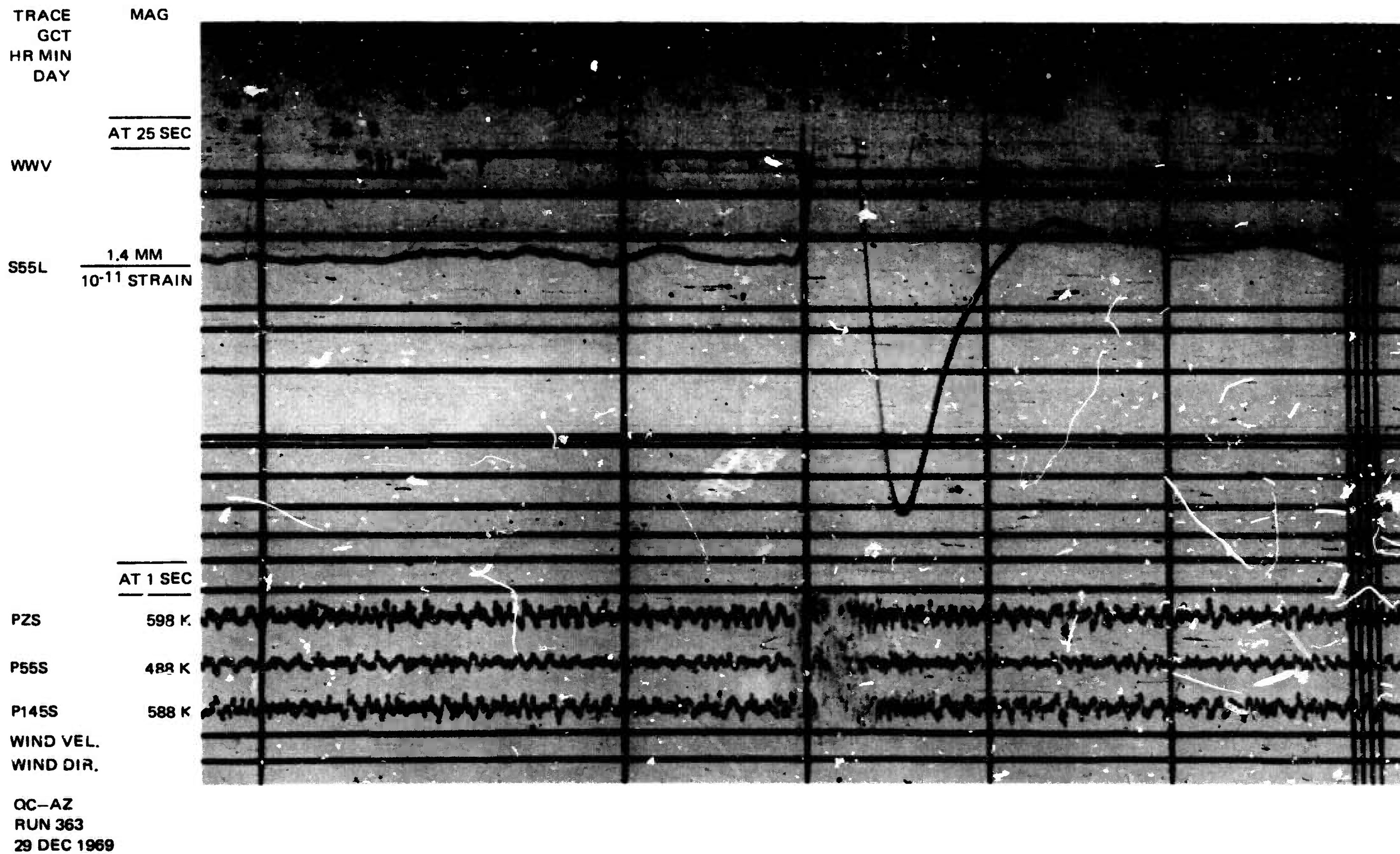

Figure 17. Reproduction of a 16-mm film recording of a local event with a single pulse of strain.

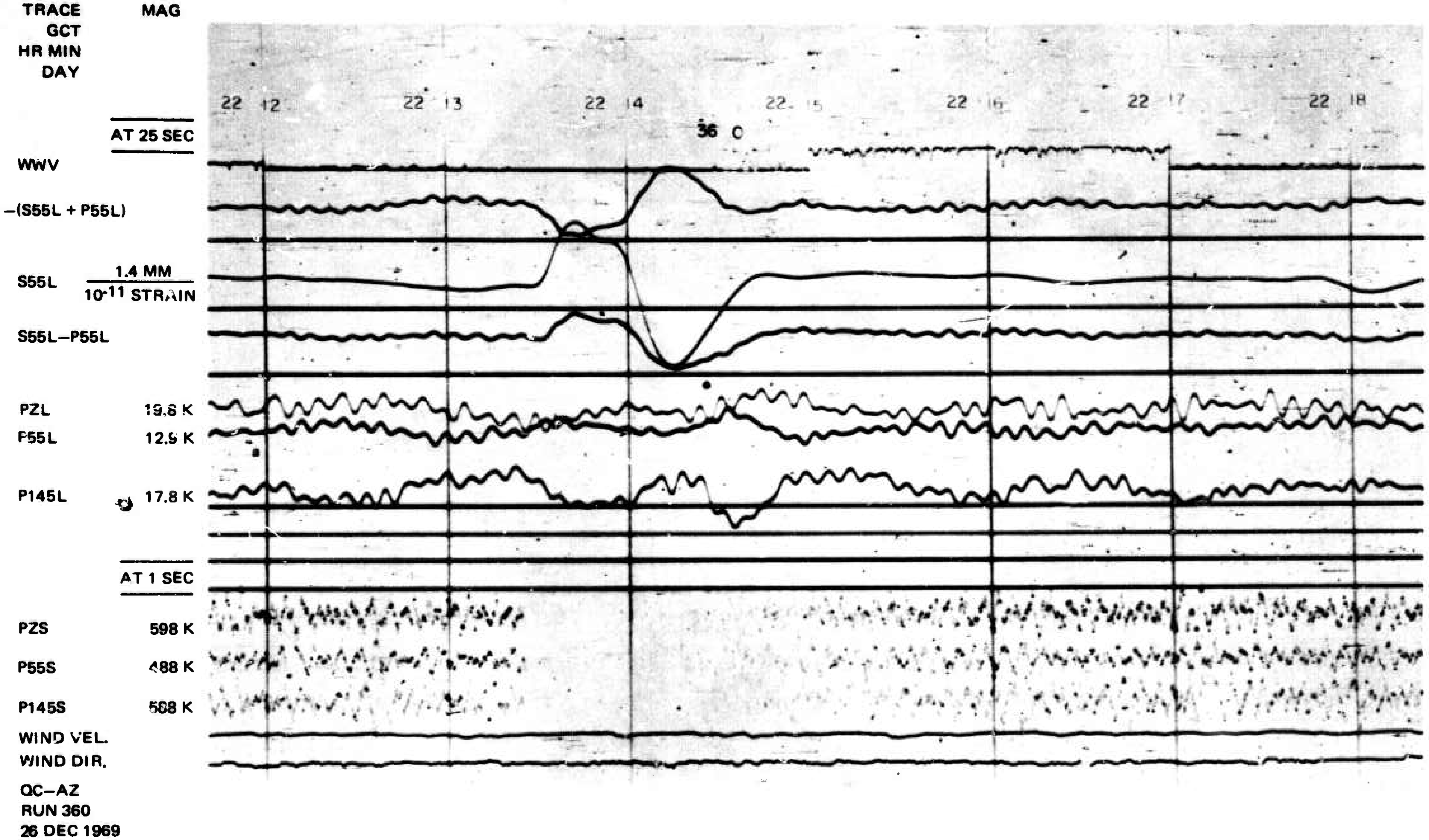

Figure 18. Reproduction of a 16-mm film recording of a local event thought to be a mine blast in the vicinity of Globe, Arizona. Note the apparent dual pulse of strain and the simultaneous response of the inertial seismographs.

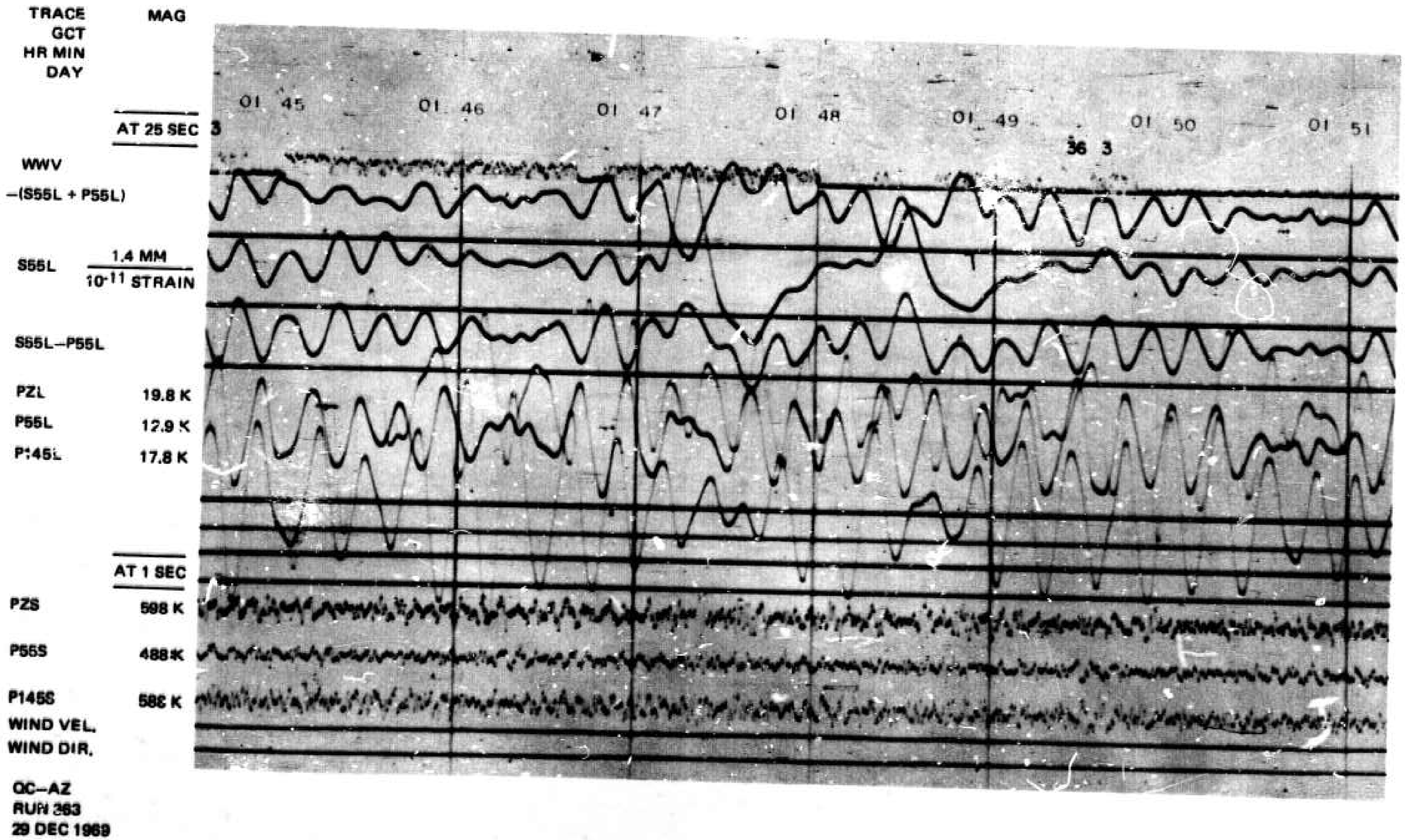

Figure 19. Reproduction of a 16-mm film recording of a surface wave train with two pulses of strain.

pulses recorded after all three components of strain seismographs are installed should correlate in some meaningful manner. If these pulses are from a local source triggered by the passage of the wave train there should be a different response from that related to a remote source.

10. OPERATE THE STRAIN-INERTIAL COMPLEX, Task d(1)

No effort was devoted to this task during this reporting period.

11. DEVELOP METHODS OF WAVE DISCRIMINATION, Task d(2)

No effort was devoted to this task during this reporting period.

12. REFERENCE

Wideman, C.J., and Major, M.W., 1967, Strain steps associated with earthquakes: Bull. Seism. Soc. Am., v. 57, no. 6, p. 1429-1444.

APPENDIX to TECHNICAL REPORT NO. 70-5

CHANNEL IDENTIFICATION NOMENCLATURE

CHANNEL IDENTIFICAION NOMENCLATURE

The nomenclature used for the recorder channel identifiers is:

Time: BCD = binary coded decimal station time

WWV = WWV time

Compensation: Comp = playback compensation channel

Data: first symbol: S = strain

P = pendulum

M = microbarograph*

W = wind

second symbol*: Z = vertical

55 = 55 degree azimuth

145 = 145 degree azimuth

V = (wind) velocity

D = (wind) direction

third symbol: L = ALPS response

U = ULPS response

X = experimental response

B = BB response

S = SP response

fourth symbol: L = low gain

1, 2, 3 = numbers assigned to similar instruments

Flag: Flag = identifier for clipping at Ithaco amplifier output

*Microbarograph channel identifiers do not have a symbol in the second symbol category.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	HQ USAF (AFTAC/VELA Seismological Center), Washington, D.C. 20333

13. ABSTRACT

The engineering model design of the strain/inertial complex is complete. The engineering model of the optical displacement transducer has been built and tests indicate that the design goals can be met. The short-term noise level is 3 x 10^{-9}m rms. Progress in preparation of the mine has been slow. The 55 deg azimuth horizontal tunnel is complete. The 325 deg azimuth tunnel is complete except for mounting holes for the instruments. The winze has been excavated down 26 ±2 ft. The fabricaton of all equipment is complete except two displacement transducers. The second and third magnets have been received with stabilized flux of 1.187T and 1.180T. This flux and the coils on hand will give transducer generator constants of 33,600 V/m/sec and 37,300 V/m/sec. Installation is progressing in parallel with completion of the mine. The following seismographs have been installed and test recordings have been made at the corresponding magnifications given for X10 view of 16-mm film: short-period inertial - 500K at 1 sec; long-period inertial - 100K at 25 sec with 6 sec notch, 20K without notch; 55 deg azimuth horizontal strain - 1.4 mm/10^{-11} strain. The strain magnification will be increased after the mine is sealed and the seismometer is insulated. Numerous strain relief pulses were recorded several hours before a 4 kg rock fell from the mine wall. Single and dual pulses of strain have been recorded for local events (S-P time 11 to 13 sec) shortly after the P arrival and before the S arrival. Multiple strain pulses have been recorded in the latter part of a teleseismic surface wave train.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Long-period strain seismograph						
Seismology						
Strain instruments						
Wave discrimination						